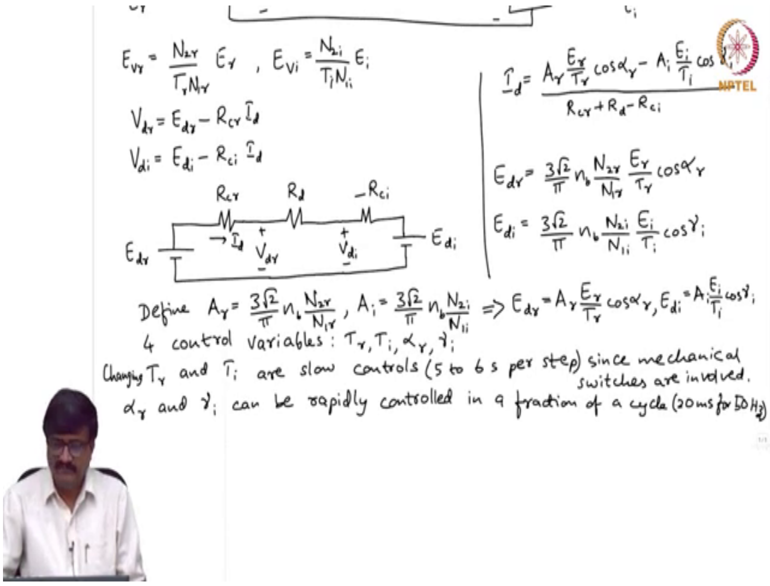
**DC Power Transmission Systems**
**Prof. Krishna S**
**Department of Electrical Engineering**
**Indian Institute of Technology, Madras**

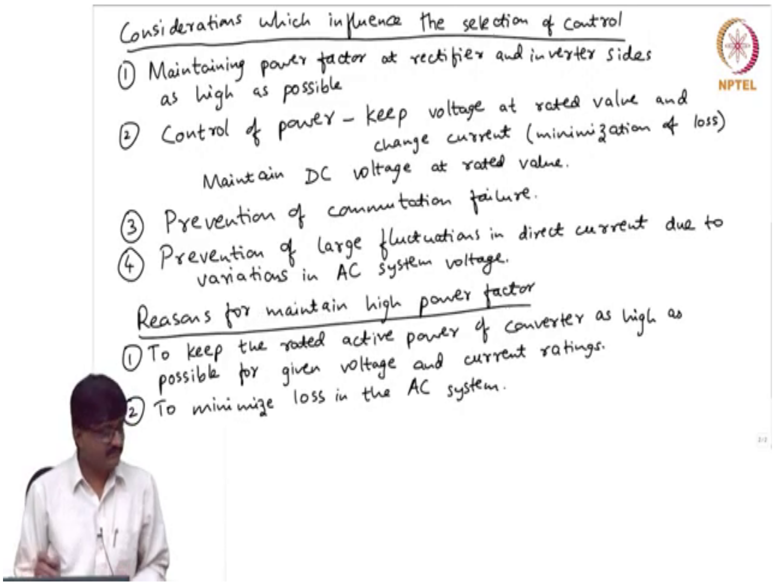
**Lecture - 55**
**Considerations that influence selection of control**

(Refer Slide Time: 00:17)




Now, the question is there are 4 control variables. Now using these 4 control variables, what should we do? So, what should be the considerations that influence the choice of the values of these 4 control variables? So, let us see how we can use this. So, we have 4 control variables at our disposal ok.

(Refer Slide Time: 00:39)




So, the considerations which influence the selection of control; that means, I want to select the values of the 4 control variables. So, what are the considerations which will help me in choosing the values of these control variables? Any guess what should be any idea based on your previous knowledge 4 control variables are there how best can we use this?

Student: We would like to maximize the power of (Refer Time: 01:26).

Maximizing, see power flow is always decided by load. See, what decides power flow? Say if some load is connected ok. Now depending on what is the requirement of the load we send some power. So, we may not want to maximize the power flow. Sometimes of course, we may try want to regulate the power flow control the amount of flow, but not always maximize.

If it is not required why do we want to maximize see under light load conditions we may not want so much power to be transferred at all. So, there is no need to always maximize power flow the any other any other consideration that may help us in deciding the values of the control variables.

Student: (Refer Time: 02:12) Power factor.

Power factor, yes power factor. Now power factor should be always.

Student: Close to unity.

Close to unity. So, it should be as high as possible that is one thing ok. Let me note that, maintaining power factor. Now when I say power factor, power factor is defined only on the AC side and there are two AC sides here; one for the rectifier one for inverter ok. So, maintaining power factor at rectifier and inverter sides.

Now at each of these locations of rectifier inverter I am talking about the AC side only. Please note power factor is always defined for the AC side, there is no definition of power factor on the DC side. At rectifier and inverter sides as high as possible yeah any other consideration?.

Now, just now in the context of maximizing power I just mentioned that we may want to regulate power instead of maximizing we want to say we want to regulate the amount of power. See otherwise if you do not regulate see in AC system which is unregulated, the amount of power is decided by Kirchhoff's laws, Kirchhoff's current law and Kirchhoff's voltage law.

So, many times we want to have control over the amount of power flow. So, here it is possible because, there is a thyristor at both the rectifier side and inverter side there is a possibility of regulating the amount of power flow. So, if I control the power so, the control of power. Now I mean what I mean here is the power that is actually transferred through the DC line.

So, if I want to control power; that means, if I want to change the amount of power, what I should do? Power is equal to the voltage into current and the DC side there is just voltage into current gives power, average voltage into average current gives power. So, I can change either voltage to change power or I can change current to change power or I can change both. Now which is desirable?

Student: (Refer Time: 04:39) voltage.

Suppose I want to change power ok, suppose I want to change power is at some value. Now I want to change it. Now for doing that will I change voltage or will I change current.

Student: No I will change current.

I will change current. Now is most of the I mean we will try to see that current is always, current is always minimized.

Student: Minimized.

Because we want to reduce losses ok. So, of current as to minimized means; voltage has to be always at value as high as possible so, almost at the rated value. So, for control of power, what we do is; keep voltage at rated value and change current. So, keeping voltage at the rated value or see rated value is the maximum possible value. So, changing current will actually result in minimization of loss and keeping voltage the rated value is actually equivalent to minimization of loss.

So, it is essentially maintaining the DC voltage near rated value. So, it is a what I am trying to say is maintain DC voltage at rated value. So, why we try to maintain a DC voltage at rated value? See the DC voltage is dependent on the AC voltage. Now due to change in conditions on the AC system, the AC voltage itself may vary. So, you in spite of variation in the AC voltage keep the DC voltage at the rated value that is the point.

So, using some of the control variables you try to keep the DC voltage constant at the rated value in spite of variations in the AC system voltage. So, variations in the AC system happen because, there are always changes in the system see the main change that is happening is always the amount of load that get gets connected to the system. So, there is a daily variation I mean; during daytime the amount of load that gets connected is different from the load that gets connected after it is dark and after it is midnight it is different.

So, there is a curve, a daily curve and there is also a weekly curve. Week days, the curve is different weekend the daily curve is different and there is a seasonal curve, summer it is different, winter it is different. So, I mean the load is something which is not constant due to which the system conditions are different and due to which the voltage at the AC system bus itself can changed slightly ok.

So, in spite of all these changes we want to maintain the DC voltage at the rated value yeah that is one consideration, any other consideration? Any other consideration? You look at the 4 control variables so looking at least the variables T r T i alpha r gamma i you may get some hint, what is gamma i?

Student: (Refer Time: 08:03).

Commutation margin angle for normal operation. Now.

Student: (Refer Time: 08:09).

We need to control this because, we do not want the commutation failure to happen. See what is commutation failure? The voltage across an outgoing valve becomes positive before it is supposed to become positive, then it will turn on even without gate pulse that should not happen that is called commutation failure if it happens ok. So, prevention of commutation failure is one of the considerations. So, if I want to prevent commutation failure it means that I should have a minimum value of, of what?

Student: (Refer Time: 08:46) naught.

Here I mean among the 4 control variables a minimum I should have gamma i to be greater than a certain threshold, otherwise it will I mean result in failure of commutation yeah. Any other any other consideration now one consideration that is very important whenever we have a power electronic device is prevention of large fluctuations in the direct current the DC side current.

So, this can be due to variations, due to variations in the AC system voltage ok. Now among these considerations, power factor is something I mean which will result in many other advantages if it is maintained at a high value. So, say why you should we read ok, reasons for it is I mean of course, from the previous knowledge that you have I mean you are all familiar with the advantages of having a high power factor but, still for sake of completeness.

Let me say a few more things about why we should maintain high power factor. Now that is because, I want to specify the reasons which are specific to this particular circuit or system that we have the DC transmission system. So, one reason for high power factor is see if you look at any equipment say converter, it has a voltage rating current rating and a volt ampere rating and it also has a power rating.

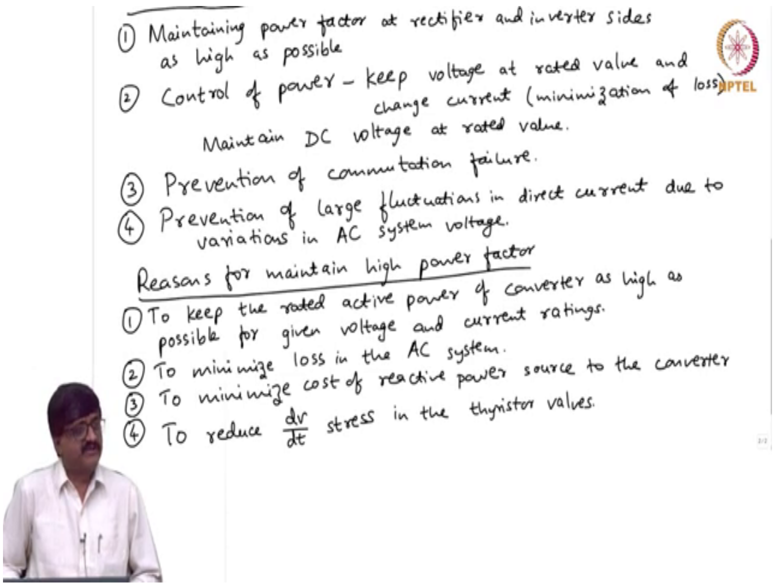
Now, for a given voltage rating or a given current rating, if the power factor is very high, the active power that can be transferred through the converter can be imagists ok. So, that is one reason. So, to keep the rated power so, when I say rated power I am not talking about the apparent power the rated active power. So, to keep the rated active power of converter as high as possible, as possible for a given voltage and current rating, for given voltage and current ratings. Now this power factor is defined on the AC side.

So, the AC side means; so, the AC side we have the AC system. So, I mean is there any advantage of having high power factor. See AC system can be always represented by a voltage source or a voltage source in series with an impedance ok. Now if I represent the AC system as a voltage source in series with an impedance which is main essentially inductive, then if there is a large power factor then there is a large drop in this equivalent inductance impedance due to which the voltage that I get may vary depending on the amount of the current.

So, as the amount of the current varies then the variation in the voltage is also present. So, there is essentially a large drop in the equivalent impedance that is representing the AC system. So, if I mean that will cause what I mean large drop means it will cause more losses in the system not only I reactive power losses, reactive power loss will also cause active power loss because, due to reactive power I need to draw large current large current will result in losses. See, that is one of the major reasons of avoiding reactive power flow.

So, if you allow reactive power flow it is actually allowing more current which will result in more loss ok. So, to minimize loss in the AC system.

(Refer Slide Time: 13:46)



Then, so, when I say, I want to keep the power factor as high as possible, what exactly is the problem I mean; if I do not keep as high as possible though we do not talk about the I mean lagging or leading power factor when it comes to presence of harmonics, if I just take fundamental frequency is the power factor lagging or leading in this case forget the harmonics for the time being.

What is happening to the power factor? It is lagging or leading? So, why am I neglecting fundamental system? We will see that shortly we will design some filters which will actually try to minimize the harmonics or some of the harmonics can be in fact, eliminated almost.

So, essentially the current that is drawn from the AC system is almost sinusoidal ok. So, essentially we are having only fundamental current or fundamental voltage and current at the AC side in the presence of filters ok. So, in that case we can talk about lagging power factor and leading power factor. So, till. Now we cannot talk about because we are not talked about it because we are not still considered filters.

So, with filters we can ignore the harmonics and say there is only fundamental, then we can talk about the lagging or leading. So, the question is whether there is a lagging power factor or leading power factor. Essentially, it is asking whether I draw reactive power from the AC system or supply reactive power to the AC system. In other words if you look at the individual currents see whether the currents are lagging the voltage or currents are leading the voltage.

Student: Lagging the voltage (Refer Time: 15:24).

Lagging the voltage. So, that means, reactive power is drawn. So, if more reactive power is drawn, I have to somehow make arrangements for supplying that. So, if the network is not able to supply. Network may not be able to supply because, I mean; at some point the last becomes large or network itself has a limitation. So, what we do is? We locally provide a reactive power source; that means, we supply reactive power using.

Student: Capacitors (Refer Time: 15:49).

Ah.

Student: Capacitors (Refer Time: 15:51).

Capacitor is one possible source ok. So, in order so, if I want to provide locally that is the cost involved, I mean; if I want to provide a additional capacitor, there is a cost involved. So, I want to in fact, the minimize the cost of the reactive power sources. So, that is why we want to keep a high value of power factor to minimize cost of reactive power source to the converter yeah any other.

There is one more advantage of maintaining high power factor which is very specific to this line commutated converter. Maybe, you would have not noticed this if there is some relationship between power factor and alpha if you take the simplest line commuted converter ignoring say the inductance for a timing for sake of simplifying the explanation. Now is there a relationship between the power factor and alpha?

Student: Both are equal.

They are equal, I mean the cos of alpha is nothing, but power factor. There is one more thing if you look at the dv by dt, the change of voltage, the voltage jumps, they are proportional to what they are dependent on alpha, but in the expression what do you see? Do you recall? Just take the simplest case without inductance there are 3 voltage jumps. So, these voltage jumps are dependent on alpha, but what is the expression do you recall? You may not remember the exact expression, but how it is dependent?

Student: Sine.

Sin alpha. Now I want to I mean should these values be voltage jumps be smaller or larger.

Student: Smaller.

As small as possible so, the dv by dt stress is reduced so; that means, alpha should be

Student: Large smaller smaller.

No for rectifier, it should be close to.

Student: 0.

0. For inverter it should be close to 180, only then it will be small ok. So, when alpha is close to 0 or 180, what is happening to power factor?

Student: It is also becoming large.

Large, so there is a relationship between power factor and dv by dt stress. So, maintaining high power factor will also result in reducing dv by dt stress. Now it is easy to explain in the case of the I mean the simplest one without inductor. Now even with inductor in addition to alpha there is a u also.

Student: (Refer Time: 18:43).

Now it is difficult to say looking at the expressions, but one can verify it. So, take a I means and a practical converter assume some value of alpha find u and see what happens. One can show that I mean one can show it is not possible to prove that in theory, but one can show in practice by calculations that maintaining high power factor is equivalent to reducing dv by dt stress even in the practical case of inductor being present on the AC side.

So, that is something not very obvious. So, let me write this as to reduce dv by dt stress in the valves thyristor valves ok. So, these are the considerations used for deciding the values of the control variables. Now which consideration is used for deciding, which control variable is something is said to be answered.

Now, a few things are very obvious. If I want to one of the considerations prevention of commutation failure to be used. Now to prevent commutation failure what should I do? I have to regulate.

Student: Gamma i.

Gamma i. So, the control variable gamma i is regulated in order to ensure that commutation failure is prevented. Then, if I want to I mean satisfy the second consideration ok, let me come to a much easier case, last one; prevention of large fluctuations, what do we do? So, which control variable can be used for prevention of large fluctuation. See the third one is very obvious, the third consideration mean prevention of commutation failure is equivalent to regulating gamma i that is one of the control variables.

See the 4 control variables are here, just now I have mentioned T r, T i, alpha r, gamma i. So, gamma i can be used for the third consideration that is prevention of commutation failure. What about preventing large fluctuation in the direct current? That means; essentially trying to regulate the current in the DC line.

Student: (Refer Time: 21:30).

So,?

Student: Alpha r.

Alpha r. Now it is it should be obvious because T r and T i slow controls, T r and T i slow controls. The only fast controls are alpha r and gamma i. Gamma i is used for the inverter commutation failure. So, all see I mean by now, you should be clear that commutation failure is not an issue for.

Student: Rectifier, rectifiers.

Rectifiers. It is an issue only for inverter that is why we are not considered gamma r, we are saying gamma i that is for the inverter. So, alpha r is the only remaining fast control variable. So, that can be used for controlling the current that is the fourth consideration. Then there are T r and Ti. So, these two are used for the other two considerations. One is maintaining a power factor the other one is maintaining the DC voltage.

So, what we do is, we use this T i, the tap on the inverter side is actually used to ensure that the voltage is regulated on the DC side. So, that is the slow control variable. So, that is not a very stringent requirement suppose for a few seconds the DC voltage is not maintained at the rated value I mean any one will not fall. But there is a problem if the current fluctuation is not avoided ok.

So, there are a few things which are not critical. So, maintaining DC voltage is not so critical if it takes a few seconds to control DC voltage it is still ok. So, we can use T i. Now T r is actually used to maintain power factor. So, we maintain power factor by keeping alpha r as low as possible ok. So, but one thing is alpha r as low as possible means one can say that keep it at what is the lowest possible value of alpha r?

Student: 0.

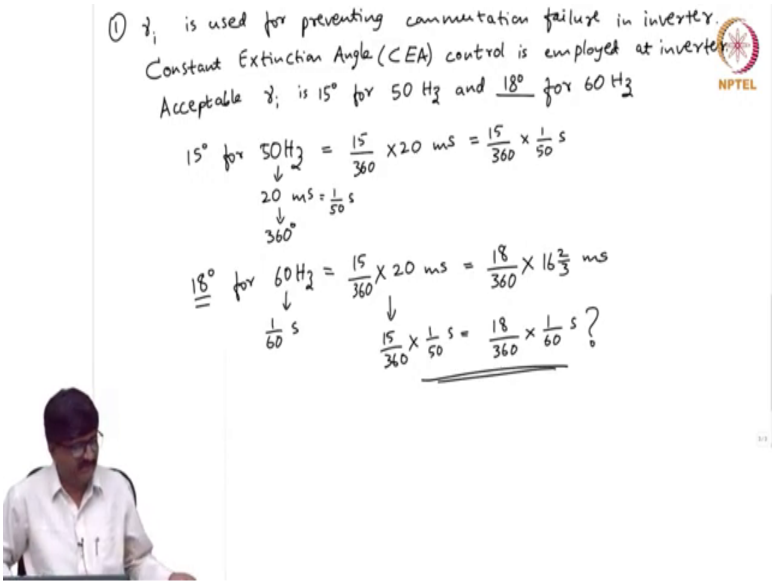
0, but we do not do that because if we keep alpha r at 0, now due to some reason suppose a large load is suddenly connected on the AC system, the AC system voltage will fall. Now we cannot increase the DC voltage because alpha r is already at.

Student: 0.

0 to leave some margin we keep alpha r at a value between 10 and 15 degrees. So, even if there is a large reduction in the AC side voltage, we can still increase the DC side voltage by

reducing alpha. So, we leave some margin ok. So, that is how it is control. So, let me summarize.

(Refer Slide Time: 24:09)




So, let me summarize. So, gamma i is used for preventing commutation failure in the inverter. So, that is the first control variable. So, this type of control is known as constant. So, what is there is a name given for gamma ray called.

Student: Extinction.

Extinction angle. So, constant extinction angle abbreviated as CEA, Constant Extinction Angle control is employed at inverter. So, the acceptable value of gamma i is 15 degrees for, now please note the acceptable values of gamma is nothing, but acceptable level of commutation margin angle, because normal operation is considered. So, it is 15 Hertz and it is dependent on frequency please note it is dependent on frequency. So, 15 degrees for 50 Hertz and if it is 60 Hertz. If it is 60 Hertz.

Student: 40 degrees.

Ah.

Student: 40 degrees.

40.

Student: 20.

20. So, what is it for 60 Hertz? Now you go back to the definition of competition margin angle. See commutation margin angle has nothing to do with angle. It has something to do with time, the time taken or the time required for the voltage to again become positive, it is only the time. So, in terms of angle it depends on frequency that is all.

Student: 18 18.

It is not obvious, see 15 degree for 50 Hertz and 18 degree, I mean; has some 15 degree for let me say 15 degree for 50 Hertz means what is the time? What is the time? What is the time in?

Student: 15 by (Refer Time: 26:59).

15 by.

Student: (Refer Time: 27:01).

No ok. Can I write this in terms of degrees? See I have said 15 degree for 100 Hertz. If I take 1 cycle it is 360 degrees, 1 cycle is 360 degrees ok. So, I want this in time so, for 50 Hertz the period is 20 milliseconds. So, 20 milliseconds corresponds to how many degrees?

Student: 360 degrees.

360 degrees. So, in so, what is this 15 degree equivalent to in terms of time?

Student: (Refer Time: 27:54) 15 by.

15 by 360 into 20 milliseconds ok. So, I want the same time for 60 Hertz, that is all. So, for 60 Hertz also I should find the angle. So, that it has the same time. So, actually same time means 15 by 360 into 20 milliseconds.

But the thing is, now the period is different. Period is not 20 milliseconds it is 16.66 milliseconds ok. And angle will also be different so, what should be the angle?

Student: 18 degrees 18.

18. Now that is because this is equal to 18 by 360 into 16 2 by 3 milliseconds. Is this I mean; I presume this is a straightforward calculation if not let me know if it is complicated let me know. So, how do I get 20 milliseconds ok, let me be let me give some more steps. How do I get 20 millisecond? It is 20 milliseconds, this is 1 by 50 seconds; 1 by 50 seconds.

So, here 1 by 60 seconds I have to take ok. So, what I am trying to say here is it is 15 by 360 into 1 by 50 seconds. So, here also I want the same thing. So, this is also I want the same thing 15 by 360 into 1 by 50 seconds. So, is this equal to 18 by 360 into 1 by 60 seconds. Are these two equal this. Is this equation correct ok, that is all I am saying. So, it is 18, so, this is 18 ok.

So, that is how we control gamma. So, there are three more control variables. So, I will summarize them in the next class ok. So, I am still I mean a few more things have to be mentioned in as far as control is concerned we look at that in the next class I will stop here.